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(54) Active single mode optical fibres and method for their fabrication

(57) An active single mode optical fiber has the core made of a rare earth doped non-oxide glass and the cladding made of an oxide glass. The glass of the core has a melting temperature lower than that of the glass of the cladding and lying within the range of the softening temperatures of the latter. In a preferred embodiment the core is made of a chalcogenide glass and the cladding is made of a lead silicate glass. To produce the fibre, a preform, obtained by introducing an element made of the non-oxide glass into the hole (2) of a capillary tube (1) made of the oxide glass, is brought to a temperature lying within the range of softening temperatures of the oxide glass and not lower than the melting temperature of the non-oxide glass, and is drawn. The capillary tube (1), during the drawing process, serves as a container for the molten glass of the core.

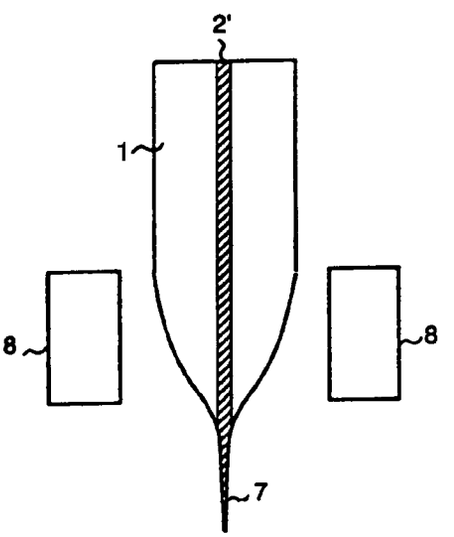

Fig. 4

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Description

The present invention relates to optical components for optical communication systems and more specifically it concerns an active single mode optical fibre with non-oxide glass core and a method for its production.

Optical fibre communication systems make more and more frequent use of optical amplifiers to compensate the attenuation of the transmitted signals resulting from propagation along the fibre, in order to avoid the need to accomplish optical/electrical conversions, and vice versa, in the repeaters. Those optical amplifiers in general comprise a section of rare earth doped optical fibre wherein the signal to be amplified and a pump signal, at a different wavelength, are sent. The most commonly used optical amplifiers use as active fibre a silica fibre, doped for instance with erbium. These amplifiers however operate on signals whose wavelength lies in the third transmission window (around 1.55 μm) and require the use of sources at that wavelength. However silica fibres, which are the most commonly used physical carrier in optical communication systems, present essentially zero dispersion in the second transmission window (wavelengths around 1.3 μm), whereas in correspondence with the third window their dispersion is high (in the order of 15 - 20 ps/nm • km). For high bit rate transmissions over long distances, this fact compels introducing into the system means for compensating the chromatic dispersion, which make the communication system complex and costly.

Optical amplifiers operating in the second transmission window have already been proposed: they use fibres made of non-oxide glass, in particular fluoride glasses, aluminium-fluoride glasses or chalcogenide glasses, doped with rare earth metals.

However the drawback of optical fibres made of non-oxide glass is that their mechanical and chemical inertia characteristics are worse than those of silica fibres (or, in general, of oxide glass fibres); moreover, the fabrication process can also cause quality problems, since the mechanical and optical characteristics of those fibres are closely linked with the "thermal history" of the glass from which the fibre is formed and, more particularly, with the number of operations which require heating the glass to a temperature exceeding glass transition temperature, since such operations may give rise to crystallisation or devitrification of the glass matrix.

To avoid the problems connected with the thermal history of the glass, it has been proposed to produce non-oxide fibres by the method known as "double crucible": see paragraphs 2.3.2 "Double crucible method" and 2.3.8 "MIR (medium-infrared fibers)" of the book "Fiber Optics Communications Handbook", by the Technical Staff of CSELT published by TAB Professional and Reference Books, Blue Ridge Summit, PA, USA, 2nd edition, 1990. This method, however presents problems in controlling the quality of the interface between the cladding and the core glasses, can cause the inclusion of gas bubbles into the fibre and, above all, it is very difficult to apply in practice when single mode active fibres (whose core diameter must be in the order of 1 - 2 mm) are to be obtained, for reasons linked with the control of the geometric dimensions of the output hole of the inner crucible.

According to the invention an active fibre and a method for its fabrication are provided which obviate the drawbacks described above.

According to the invention a single mode active fibre is provided whose core is made of a rare earth doped, non-oxide glass, wherein the cladding is made of an oxide glass and wherein, furthermore, the core is made of a glass whose melting temperature is lower than that of the cladding glass and lies within the range of softening temperatures of the latter.

The term "range of softening temperatures" means, in this description and in the claims which follow, the range between the glass transition temperature Tg (where the glass has a viscosity of 10^{12} Pa • s) and the temperature at which the glass has a viscosity of 10^{4} Pa • s (viscosity at which the "gob" falls down by gravity and the fibre can be drawn with minimum force).

A fibre of this kind eliminates the mechanical resistance and chemical inertia problems of fibres completely made of non-oxide glass, since the cladding (which makes up most of the material of the single mode fibre) is made of an oxide glass. Moreover the aforesaid glasses can be active both in the second window (if doped with Pr and Dy) and in the third window (if doped with Er) and in this latter case, as is well known, they present a broader and flatter amplification band than oxide glasses.

Important aspects to be taken into account in choosing the two glasses to be used in a fibre of this kind are given by the thermal expansion coefficient and by the refractive index of the glasses themselves. Specifically, the two glasses must have, at temperatures lower than glass transition temperature, essentially similar thermal expansion coefficients, in order to prevent the cladding to induce stresses on the core or vice versa while the fibre being drawn cools off. In regard to refractive indexes, they must be such that the numerical aperture allows obtaining cores whose radius is in the required order of magnitude. The numerical aperture is given by $NA = (n_1^2 - n_2^2)^{1/2}$, with n_1, n_2 = refractive indexes of the core and of the cladding respectively, and it is linked to radius r of the core and to wavelength λ by relation $\lambda = 2\pi r \cdot NA/2.405$. Suitable numerical apertures range between 0.3 and 0.5.

Non-oxide glasses which can be used in the presence of an oxide glass cladding can be, for instance, chalcogenide glasses, aluminum fluoride glasses, or phosphate-fluoride glasses.

Examples of chalcogenide glasses which can be used to obtain active fibre optical amplifiers are Ge-S

based multicomponent glasses, particularly Ga-Ge-S based glasses such as Ba-Ga-Ge-S, Pb-Ga-Ge-S, As-Ga-Ge-S glasses; examples of compositions for such glasses are reported in the paper "Rare-earth-doped Multicomponent Ge-based Sulphide Glasses" presented by B. G. Aitken and R. S. Quinby at the 10th International Symposium on Non-Oxide Glasses, Corning, NY USA, 22 - 24 June 1996. These glasses have glass transition temperatures Tg ranging from a minimum of about 325° C (for glasses containing As) to a maximum of about 475° C (for glasses containing Ba), melting temperatures in the order of 700 - 740° C, thermal expansion coefficients α (for temperatures lower than Tg, particularly temperatures in the range 30 to 300° C) ranging from a minimum of about $11 \cdot 10^{-6}$° C^{-1} (for glasses containing Ba or As) and a maximum of about $16 \cdot 10^{-6}$° C-1 (for glasses containing As), and refractive index ranging from 2 to about 2.5.

Oxide glasses with glass transition and melting temperatures, thermal expansion coefficients and refractive indexes compatible, for the purposes of the present invention, with those of the aforesaid non-oxide glasses are specifically lead silicate glasses with high lead oxide content, preferably between 30 % and 70 % (molar percentages), whose refractive index varies from 1.69 to 2.14. In choosing the specific composition it should be kept in mind that glasses whose lead oxide content is close to the upper limits of the range have thermal expansion coefficients which are very similar to those of chalcogenide glasses and refractive indexes yielding the required numerical aperture for the fibre, but they may present excessively low glass transition temperatures; on the contrary, glasses whose lead oxide content is close to the lower limits of the range have suitable glass transition temperatures but may present excessively low thermal expansion coefficients and refractive indexes. Glasses whose lead oxide content is within the preferred range represent in any case a good compromise solution, also taking into account that any stresses induced in the drawing process can be eliminated with an annealing operation at temperatures lower than the glass transition temperature Tg of the core glass.

Alternatively, instead of binary SiO_2-PbO glasses, lead silicate glasses also containing minor percentages of additional oxides, e. g. TiO_2, can be used: the presence of these additional oxides allows, as is well known to the person skilled in the art, modifying the characteristics of a lead silicate glass in order to obtain the required compatibility of all parameters of interest in the two glasses.

Glasses containing oxides of the M_2O_5 type, where M is Nb or Ta, instead of PbO are also suitable. The refractive indexes of said glasses also exceed 2.

Suitable aluminium fluoride glasses are multicomponent glasses, for instance glasses containing, in addition to AlF_3, fluorides of alkaline or alkaline-earth metals. By way of example, one can mention glasses whose constituents and the respective percentages are provided in the table which follows (molar percentages):

AlF_3 (30 - 40%) MgF_2 (5 - 12%) CaF_2 (15 - 30%) SrF_2 (6 - 10%)

BaF_2 (5 - 10%) LiF (3 - 12%) NaF (0 - 12%)

Aluminum fluoride glasses in general have quite a low refractive index (1.44 - 1.45), so that the oxide glass will generally be a glass based on silica doped with a suitable element which lowers the refractive index, such as F or B_2O_3.

The invention also provides a method for the fabrication of the aforesaid fibre, wherein a preform comprising a cladding and a core is drawn, in which the ratio between the diameters corresponds to that required to obtain a single mode active fibre, characterised in that for preform production an oxide glass capillary tube is used as cladding, in the hole of which there is introduced an element of non-oxide glass, whose melting temperature is lower than that of the oxide glass and lies within the range of softening temperatures of the latter and, for the drawing process, the preform is brought to a temperature lying within said range and not lower than the melting temperature of the non-oxide glass.

The non-oxide glass element can be introduced into the capillary in its molten state, by capillarity or by pouring, or in its solid state, in the form of a rod.

The non-oxide glass element is conveniently made of a chalcogenide glass, specifically a Ge-S-based multicomponent glass, and preferably a Ga-Ge-S-based glass such as a Ba-Ga-Ge-S, Pb-Ga-Ge-S, As-Ga-Ge-S glass. In this case the oxide glass element can be made of a lead silicate glass with high lead oxide content, preferably between 30 % and 70 % (molar percentages), or of a glass containing, in addition to silica, Nb_2O_5 and Ta_2O_5.

As can be clearly seen, with the described method the fibre is obtained either by starting from the non-oxide glass already in its molten state, or by drawing a cold-formed preform. Thus, there is a single high temperature operation on the non-oxide glass and therefore the devitrification risk connected to multiple heating operations to which said glass is subjected using the known methods is essentially eliminated.

The glasses used have preferably melting temperatures (for the non-oxide glass) and softening temperatures (for the oxide glass) ranging between about 700 and 750° C, and such refraction indexes as to give rise, in the drawn fibre, to a numerical aperture ranging between 0.3 and 0.5.

The invention shall now be described in more detail with reference to the attached drawings, which show some phases of the method according to the invention, considering by way of example the case in which a fibre with chalcogenide glass core and lead silicate glass cladding is to be obtained.

The first step is fabricating a preform, starting from a lead silicate glass tube 1 (with, for instance, a lead oxide content between 30 and 70 %) with a capillary

hole 2, destined to form the cladding of the preform. The preform shall have, as usual, radial dimensions which are about 100 times larger than those of the final fibre, and therefore the outer diameter of tube 1 shall be in the order of ten mm (e.g. 12 - 20 mm, taking into account that the outer diameter of a single mode fibre is about 125 μm) and the hole shall have a diameter of about 0.2 mm (for a fibre with a core diameter of about 2 μm). Lead silicate glass (or in general oxide glass) tubes with capillary holes and outer and inner diameters of the order of magnitude indicated are commercially available or can be easily produced, in a way well known to the person skilled in the art.

To form the core, a chalcogenide glass (specifically a Ba-Ga-Ge-S, Pb-Ga-Ge-S, As-Ga-Ge-S glass), previously doped in any suitable way with rare earth metals (e. g. Pr, Dy or Er depending on the intended transmission window) in the amounts required to obtain an optical amplifier is introduced into the capillary hole 2.

In a first embodiment the chalcogenide glass is melted beforehand and introduced into the capillary hole while in its molten state. For this purpose, tube 1 can be immersed in a crucible 3 (Figure 1) containing molten glass 10 and capillarity can be exploited. Alternatively, as can be seen in Figure 2, molten glass 10 contained in a crucible again indicated as 3 can be poured into hole 2. In this second case it may be convenient for the upper end of tube 1 to present a flare 4; moreover, the lower end of tube 1 shall be advantageously connected to an aspiration system, not shown.

Note that the time required for the molten glass to fill by capillarity the cavity of a tube (whose length shall be in the order of a few centimetres) is such that there is no substantial cooling of the glass; yet, it may be useful to pre-heat the tube of lead silicate glass.

In a second embodiment, shown in Figure 3, a rod 5 of the chalcogenide glass, at ambient temperature, is introduced into hole 2.

As a result of the aforesaid operations a preform is obtained, comprising a cladding constituted by tube 1 and a core 2' (Figure 4). The subsequent operation entails drawing the preform to obtain fibre 7. For the drawing operation, the preform is brought to a temperature of the order of 700 - 750° C. At these temperatures the chalcogenide glasses indicated above melt, whereas the lead silicate glass softens (i. e. its viscosity is between 10^{12} Pa • s and 10^4 Pa • s) and it can be drawn with a force that is the greater the temperature is closer to the glass transition temperature. Outer tube 1 in practice acts as "container" for the core, and its softening guarantees a good uniformity of the cladding-core interface. During the drawing operation, the fibre is also provided with possible external protective coatings. The drawing plant is wholly convention and the Figure shows only the heating means 8.

If the cooling of the fibre being drawn could give rise to stresses of the core on the cladding or vice versa, for instance because of an excessive difference in the thermal expansion coefficients of the two glasses in the temperature range between the glass transition temperature and ambient temperature, before applying the coating it is also possible to subject the fibre to an annealing operation, at temperatures lower than the glass transition temperature Tg of the chalcogenide glass (about 300° C).

It is evident that the description above is provided solely by way of non limiting example and that variations and modifications are possible without thereby departing from the scope of the invention.

Claims

1. Single mode active optical fibre with a core made of rare earth doped non-oxide glass, characterised in that the fibre includes a cladding made of oxide glass and in that the core glass has a melting temperature lower than that of the cladding glass and lying within the range of the softening temperatures of the latter the range of softening temperatures being the range between the glass transition temperature and the temperature at which the glass has a viscosity of 10^4 Pa • s.

2. Optical fibre as claimed in claim 1, characterised in that the melting temperature of the core glass and the softening temperature of the cladding glass are of the order of 700 - 750° C.

3. Optical fibre as claimed in claim 1 or 2, characterised in that the glasses of the cladding and of the core have such refractive indexes as to yield a numerical aperture between 0.3 and 0.5.

4. Optical fibre as claimed in any of the previous claims, characterised in that the core is made of a chalcogenide glass and the cladding is made of a lead silicate glass or of a SiO_2-M_2O_5 glass, where M is a metal chosen between Nb and Ta.

5. Optical fibre as claimed in claim 4, characterised in that the chalcogenide glass is a Ge-S-based multicomponent glass.

6. Optical fibre as claimed in claim 5, characterised in that the Ge-S based multicomponent glass is a Ga-Ge-S glass.

7. Optical fibre as claimed in claim 6, characterised in that the Ga-Ge-S glass is chosen among Ba-Ga-Ge-S, Pb-Ga-Ge-S and As-Ga-Ge-S glasses.

8. Optical fibre as claimed in any of claims 4 to 7, characterised in that the lead silicate glass is a glass containing 30 to 70 % PbO, in molar percentage.

9. Optical fibre as claimed in claim 8, characterised in that the lead silicate glass contains TiO_2.

10. Method of fabricating single mode active optical fibres with a core made of a rare earth doped non-oxide glass, wherein a preform comprising a cladding (1) and a core (2') is drawn, characterised in that for preform fabrication a capillary tube (1) made of an oxide glass is used as a cladding and an element of the non-oxide glass, having a melting temperature lower than that of the oxide glass and lying with the range of softening temperatures of the latter is introduced into the capillary hole (2) of said tube (1), and, for the drawing, the preform is brought to a temperature within said range and not lower than the melting temperature of the non-oxide glass, so that the capillary tube (1), during drawing, serves as a container for the molten glass of the core.

11. Method as claimed in claim 10, characterised in that the non-oxide glass element is introduced into the hole (2) in its molten state.

12. Method as claimed in claim 11, characterised in that the non-oxide glass element is introduced into the hole (2) by capillarity.

13. Method as claimed in claim 11, characterised in that the non-oxide glass element is poured into the hole (2).

14. Method as claimed in claim 13, characterised in that in the course of the pouring process a vacuum is created inside the hole (2).

15. Method as claimed in any of claims 11 to 14, characterised in that the capillary tube (1) is pre-heated.

16. Method as claimed in claim 10, characterised in that the non-oxide glass element is introduced in the hole (2) without heating, in the form of a rod (5).

17. Method as claimed in any of claims 10 to 16, characterised in that for the drawing process the preform is brought to a temperature of the order of 700 - 750° C.

18. Method as claimed in any of claims 10 to 17, characterised in that glass compositions with such refractive indexes as to yield a numerical aperture between 0.3 and 0.5 are used for the non-oxide glass and the oxide glass.

19. Method as claimed in any of claims 10 to 18, characterised in that a chalcogenide glass is used as non-oxide glass and a lead silicate glass or a SiO_2-M_2O_5 glass, where M is a metal chosen between Nb and Ta., is used as oxide glass

20. Method as claimed in claim 19, characterised in that a Ge-S-based multicomponent glass, preferably a Ga-Ge-S glass and more preferably a glass chosen in the group comprising Ba-Ga-Ge-S, Pb-Ga-Ge-S, As-Ga-Ge-S is used as chalcogenide glass.

21. Method as claimed in claims 19 or 20, characterised in that a glass containing from 30 to 70 % PbO, in molar percentage, is used as lead silicate glass.

22. Method as claimed in claim 21, characterised in that a glass containing also minor percentages of TiO_2 is used as lead silicate glass.

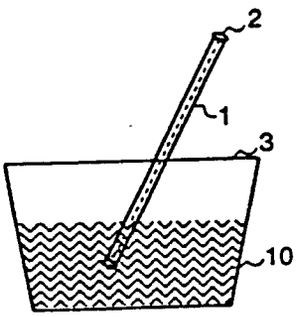

Fig. 1

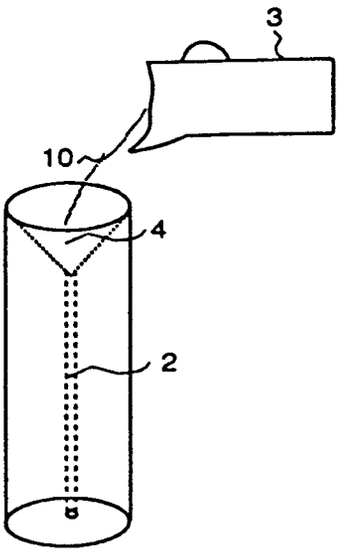

Fig. 2

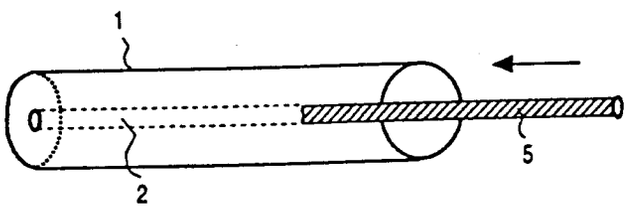

Fig. 3

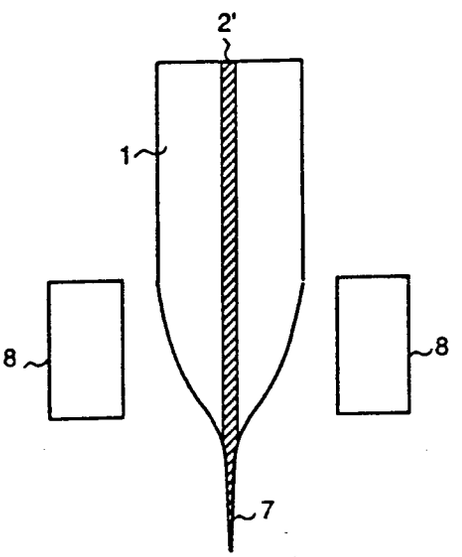

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 97 12 0151

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 3 901 996 A (Y.HASEGAWA ET AL.) * claim 1 * ---	1-3	C03C13/04 C03B37/027 C03B37/012
X	EP 0 716 048 A (AT&T CORP.) * column 3, line 40 - column 4, line 8 * ---	1-5,10, 11	
A	WEI K ET AL: "PR3+-DOPED GE-GA-S GLASSES FOR 1.3 M OPTICAL FIBER AMPLIFIERS" JOURNAL OF NON-CRYSTALLINE SOLIDS, vol. 182, no. 3, 2 March 1995, pages 257-261, XP000488203 ---	5-7	
A	DATABASE WPI Section Ch, Week 8845 Derwent Publications Ltd., London, GB; Class L01, AN 88-319483 XP002057123 & JP 63 236 729 A (HISANKABUTSU GLASS KENKYU) , 3 October 1988 * abstract * ---	10,11,13	
A	PATENT ABSTRACTS OF JAPAN vol. 016, no. 198 (C-0939), 13 May 1992 & JP 04 031333 A (NIPPON TELEGR & TELEPH CORP), 3 February 1992, * abstract * -----	10	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
C03C
C03B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 February 1998	Reedijk, A

CATEGORY OF CITED DOCUMENTS

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